Neuroscience Vol. 5, pp. 195 to 206
Pergamon Press Ltd 1980. Printed in Great Britain
© IBRO
0306-4522/80/0201-0195$02.00/0

215

COMMENTARY

MIND–BRAIN INTERACTION: MENTALISM, YES; DUALISM, NO

R. W. SPERRY
California Institute of Technology, Division of Biology, Pasadena, CA 91125, U.S.A.

Abstract—A traditional working hypothesis in neuroscience holds that a complete account of brain function is possible, in principle, in strictly neurophysiological terms without invoking conscious or mental agents; the neural correlates of subjective experience are conceived to exert causal influence but not mental qualities *per se*. This long established materialist–behaviorist principle has been challenged in recent years by the introduction of a modified concept of the mind–brain relation in which consciousness is conceived to be emergent and causal. Psychophysical interaction is explained in terms of the emergence in nesting brain hierarchies of high order, functionally derived, mental properties that interact by laws and principles different from, and not reducible to those of neurophysiology. Reciprocal upward and downward, interlevel determination of the mental and neural action is accounted for on these terms without violating the principles of scientific explanation and without reducing the qualities of inner experience to those of physiology. Interaction of mind and brain becomes not only conceivable and scientifically tenable, but more plausible in some respects than were the older parallelist and identity views of the materialist position.

This revised concept of consciousness as causal, with its recognition of mental phenomena as explanatory constructs in science, has brought a marked change during the past decade in the scientific status of consciousness and of mental and cognitive phenomena generally. Resultant mentalist trends within science have been accompanied also by a corollary rise in acceptance of various mentalist-related concepts and dualist beliefs in the supernatural, the paranormal and in unembodied forms of conscious existence that receive no logical support from the new mind–brain concepts of neuroscience. Reasons are advanced to show that our latest mind–brain model is fundamentally monistic and not only fails to support dualism, but serves to further discount fading prospects for finding dualist forms or domains of conscious experience not embodied in a functioning brain.

THE NEW INTERACTIONISM

WHEN two eminent authorities of science and philosophy, of the stature and influence of Sir John Eccles and Sir Karl Popper, join forces to affirm dualistic beliefs in the reality of the supernatural and the existence of extraphysical, unembodied agents to challenge some of the most fundamental precepts of science, one is impelled to take more than passing notice. Regardless of one's personal convictions and reactions, the kind of public message that is conveyed, directly and indirectly, by their book *The Self and Its Brain—An Argument for Interactionism* (POPPER & ECCLES, 1977) along with Eccles's more recent volume *The Human Mystery* (ECCLES, 1979) and the potential impact of these on the intellectual perspectives of our times become a matter of some concern. Such considerations, and the fact that my own views and writings are cited in support of some of the key concepts and as being in alignment with dualist interactionism, prompt this effort to clarify certain points that otherwise leave erroneous impressions.

Before I attempt to focus on specifics, it will help to mention broadly that whereas Sir John Eccles and I have similar outlooks with many highly congenial perspectives, aims and values, we do, however, share certain friendly differences in regard to the nature and locus of consciousness and the support of dualism. I have always favored monism, and still do. Sir John tells me that I am a dualist and I respond, 'Only if the term is redefined to take on a new meaning quite different from what it traditionally has stood for in philosophy.' Dualism and monism have long represented a dichotomy that offers opposing answers to one of man's most critical and enduring concerns, namely, Can conscious experience exist apart from the brain? Dualism, affirming the existence of independent mental and physical worlds, says 'yes' and opens the door to a conscious after-life and to many kinds of supernatural, paranormal and other-worldly beliefs. Monism, on the other hand, restricts its answers to one-world dimensions and says 'no' to an independent existence of conscious mind apart from the functioning brain.

In recent years there has arisen some real need to change and sharpen definitions of certain philosophic terms to fit our new views in neuroscience. However, in the case of monism and dualism, I see no advantage in changing the classic definitions. We greatly need terms by which to distinguish the critical dichotomy regarding the potential separability of brain and conscious experience during life as well as after. Dualism and monism have long served this need in the past and seem best qualified to continue.

At the same time I am in strong agreement with Eccles in rejecting both materialism (or physicalism) and reductionism—or at least what these terms predominantly stood for prior to the mid-1960s. Since 1965 I have referred to myself as a 'mentalist' and since the mid-1930s have firmly renounced reductionism in the philosophic, 'nothing but' sense to be explained below. However, in the case of the terms 'mentalism' and the opposing 'materialism', and the form of dichotomy these two imply, some change and sharpening of definitions is now called for by our modified mind–brain concepts. On our new terms, which I will outline below, 'mentalism' is no longer synonymous with 'dualism' nor is 'physicalism' the equivalent of 'monism'. By our current mind–brain theory, monism has to include subjective mental properties as causal realities. This is not the case with physicalism or materialism which are the understood antitheses of mentalism, and have traditionally excluded mental phenomena as causal constructs. In calling myself a 'mentalist', I hold subjective mental phenomena to be primary, causally potent realities as they are experienced subjectively, different from, more than, and not reducible to their physicochemical elements. At the same time, I define this position and the mind–brain theory on which it is based as monistic and see it as a major deterrent to dualism. In order to better explain these distinctions, it will be helpful to start at the beginning and to follow the conceptual developments step-by-step as they occurred.

My long-trusted materialist logic was first shaken in the spring of 1964 in preparing a nontechnical lecture on brain evolution in which I was extending the concept of emergent control of higher over lower forces in nested hierarchies to include the mind–brain relation. I found myself concluding with the then-awkward notion that emergent mental powers must logically exert downward causal control over electrophysiological events in brain activity. Mental forces were inferred to be equally or more potent in brain dynamics than are the forces operating at the cellular, molecular and atomic levels (SPERRY, 1964). Again, in September of that year, when preparing a paper for the Vatican Conference on Brain and Consciousness organized by John Eccles, it occurred to me that the functionist interpretation of consciousness that I had outlined in the early 1950s (SPERRY, 1952), and still favor, must also logically call for a functional (and therefore *causal*) influence of conscious experience in brain activity. It was obvious that these combined concepts, were they to hold up, would provide a new approach to the old question of how consciousness may be of functional use and exert a causal control role in brain processing. The kind of psychophysical relation envisaged showed how mind could influence matter in the brain, making the interaction of such different things as mental states and physical events logically understandable at long last on terms that were scientifically acceptable.

In the mid-sixties, such interactionist concepts were still complete heresy to those of us in neuroscience and I did not venture to push them at this conference beyond mild reference to 'a view that holds that consciousness may have some operational and causal use'. To this Eccles responded by asking 'Why do we have to be conscious at all? We can, in principle, explain all our input–output performance in terms of activity of neuronal circuits; and, consequently, consciousness seems to be absolutely unnecessary' (Eccles, 1966, p. 248). This is, of course, what we had all been taught and believed for decades, not only in science but also (by the great majority) in philosophy. The idea that the objective physical brain process is causally complete in itself without reference to conscious or mental forces represents the central premise of behaviorism and of scientific materialism in general and has long served as a prime basis for the renunciation of the phenomena of subjective experience as explanatory constructs in science. Eccles, however, already at the time a dualist by faith, training and publication (ECCLES, 1953), went on to add: 'I don't believe this story, of course; but at the same time, I do not know the logical answer to it.' Nevertheless, his considered conviction on the first point was firmly reiterated in a later session, 'I am prepared to say that as neurophysiologists we simply have no use for consciousness in our attempts to explain how the nervous system works . . .' (ECCLES, 1966, p. 250).

I argued the point briefly but was not yet sufficiently versed in my new-found answer to pursue it vigorously at the time. In the ensuing weeks and months, however, in pondering the unifying role of callosal activity, the ideas kept recurring and the more I thought about them, the better they looked. A trial run the next April to our Caltech Division of Biology convinced me that reductive neuroscience and biology were not exactly ready for this kind of thinking. However, I decided to proceed anyway with a presentation the following month in a humanist lecture at the University of Chicago for the volume, *New Views of the Nature of Man*, edited by J. PLATT (1965). For the purpose of this lecture, I worked the new mind–brain ideas into a discussion of holist-reductionist issues, emergent downward control, and 'nothing but' fallacies in human value systems, in a broad refutation of the then prevalent '. . . mechanistic, materialistic, behavioristic, fatalistic, reductionistic view of the nature of mind and psyche'. It was on this occasion that I openly changed my alignment from behaviorist materialism to antimechanistic and nonreductive mentalism (—as the term 'mentalism' is used in psychology in contrast to behaviorism; not, of course, in the extreme philosophic sense that would deny material reality). At the same time, I described this new position as a unifying scheme that 'would eliminate the old dualistic confusions' in favor of 'a single "this world" measuring stick for evaluating man and existence'.

The main thesis of the essay, as in the Popper–Eccles book, was psychophysical interaction, its logi-

cal support and its scientific, philosophic and human value implications. Essentially, it presented the view that subjective experience as an operational derivative and emergent property of brain activity plays a prime causal role in the control of brain function. It differed from previous emergent theories of consciousness, from C. LLOYD MORGAN (1923) onward, in that earlier emergent views of mind had been conceived in terms that were parallelistic, double aspect, or epiphenomenal, and had rejected any direct causal influence of mental qualities on neural processing (KÖHLER, 1961). The thesis was focussed on contradicting the traditional, mechanistic assumption expressed by Eccles that brain processing can be completely accounted for, in principle, without including conscious phenomena. Presented in terms of neuronal circuitry and concepts of neuroscience, it seemed to counter and refute, for the first time on its own grounds, the classic physicalist assumption of a purely physical determinancy of the CNS. The subjective mental phenomena had to be included. Mind–brain interaction was made a scientifically tenable and even plausible concept without reducing the qualitative richness of mental properties. The overall aim of the paper, as in the Popper–Eccles volume, was to show that this recognition of the primacy of conscious mind as causal would alter profoundly the value implications of science which were being downgraded by the then strongly dominant philosophy of reductive mechanistic materialism.

At the same time, the proposed mind–brain model was taken to undermine dualism as well by explaining conscious experience in terms that would make mind inextricably inseparable from, and embodied in, the functioning brain. It provided a rationale for the evolution of mind from matter and also the emergence of mind from matter in brain development. Presented as a 'conceptual skeleton on which to build a body of philosophy', it was described as a scheme that 'would put mind back into the brain of objective science and in a position of top command'.

When the reprints arrived, I sent my new mind–brain 'answer' to Eccles who previously had expressed little, if any, active interest in the holist-reductionist issues (ECCLES, 1966). I was delighted to see by his next IBRO presentation (ECCLES, 1968) that he had clearly joined our ranks as an ardent anti-reductionist denouncing 'the materialistic, mechanistic, behavioristic, and cybernetic concepts of man ...' Reversing his earlier stand on the uselessness of consciousness for a full account of brain function, Eccles has since lent his support to the new logic for the causal influence of mind over neural activity. On these points I believe we have remained in good general agreement (see ECCLES, 1973). It is in regard to the nature of the causal influence and to the use of these new mind–brain concepts to support dualism that our critical differences arise. Other differences concerning the relation of consciousness to the right hemisphere, to language, to animals, and to self consciousness, though of some concern, are of secondary importance in the present context and will not be pursued here. However, in the case of those differences that pertain to the mind–brain problem and to dualist interactionism we deal, as Sir John has very ably emphasized, with more than ordinary professional and academic interpretations. At stake are central key concepts that directly involve fundamental convictions regarding the nature of man's inner being, physical reality, the meaning of existence, and related matters of ultimate concern. Because perspectives in this area profoundly shape human value systems and societal decision-making and hence human destiny, we mutually agree that these issues must take precedence over other considerations.

Looking back today, it seems clear that I quite failed to foresee how the new mind–brain solution might be taken to support dualism. Even though dualism and mentalism had long been associated and even equated, and some colleagues had forewarned that I might accordingly be accused of dualism, I nevertheless supposed the new mentalist–dualist distinctions to have been sufficiently clarified (see especially, SPERRY, 1970*b*). Back in the 1960s dualist views were no threat to science and accordingly, it seemed much more important in those years to combat the more prevalent errors of materialism, mechanism, behaviorism and reductionism, than to emphasize the conjoint logic against dualism. Again, the finer points involved here are better and more easily explained if we continue to follow the chronological approach.

GROWING SCIENTIFIC ACCEPTANCE

After waiting more than three years during which the feedback was mostly positive, especially from humanist groups, I tested the theory more directly in the scientific community by presenting it at a neurological meeting (SPERRY, 1970*a*) and then to the National Academy of Sciences (SPERRY, 1969*a*) with a follow-up printed version in the *Psychological Review* (SPERRY, 1969*b*). The result was a wide exposure, increased by several reprintings and a critique (BINDRA, 1970) and reply (SPERRY, 1970*b*), within those disciplines most knowledgeable and most apt to be critical. In these conjectural areas where the concepts are still beyond any direct experimental verification, the next best test is to put them in the marketplace to be churned over by hundreds of minds from all different angles. In this respect the years 1969 to 1971 were the critical years for this theory. No logical flaw nor prior statement, so far as I know, has yet come to light.

By the early 1970s, the modified concept of consciousness as having causal efficacy began to gain substantial scientific acceptance particularly in psychology in a pervasive resurgence of mentalism and anti-behaviorism that is still gathering momentum (KANTOR, 1978). Essentially, the new interpretation

brought a logical change in the scientific status of subjective experience replacing behaviorist principles with a mentalist or cognitivist paradigm. Psychologists could now refute the logic and principles of behaviorism and refer directly to the causal influence of mental images, ideas, inner feelings, and other subjective phenomena as explanatory constructs. The suddenness with which this began to occur was almost explosive in the cognitive disciplines (PYLSHYN, 1973). The movement has been referred to as the 'cognitive revolution' (DEMBER, 1974) and also variously as the 'humanist', 'consciousness' or 'third' revolution (MATSON, 1971) and has extended also into philosophy, anthropology (FREEMAN, 1979) and neuroscience (BUNGE, 1977; JOHN, 1976; MACKAY, 1978).

Eccles's increasingly vigorous campaign for dualist interactionism during this same period has followed on a curve that closely parallels the above. A similar curve can be drawn for a rising public belief in psychic, paranormal and related mentalist phenomena, along with mysticism, occultism, and other dualist beliefs in the supernatural and in other-worldly forms of existence. Some of these have logical support in the new mind–brain concepts; others are bolstered only spuriously by association. There is good reason to think that the gains made by these mentalist-related developments during this period have been substantially aided, directly and indirectly, by the appearance in neuroscience of a plausible logical answer by which to counter the basic premises and principles of the traditional behaviorist paradigm. Without a convincing alternative to replace the physicalist logic, we would be back today much where we were in the mid-1960s, i.e. where materialist–behaviorist reasoning effectively outweighed all the intuitive, natural and omnipresent subjectivist pressures and arguments, and where cognitive psychology remained in principle a science of para- and epiphenomena. More specifically, the increasing assurance with which Eccles has been able in recent years openly to proclaim dualist arguments not visible in the 1964 conference suggests that he has developed in the interim a new 'logical answer' that was not perceived earlier.

HOW MANY NEW MIND–BRAIN SOLUTIONS?

A first question that needs to be considered is whether the set of concepts which Eccles currently uses to support dualism (Karl Popper's arguments will be discussed separately) is significantly different from that which I proposed as a nondualist, monistic solution. Have we independently come on two different answers for mind–brain interaction, or is it a matter of different interpretations of basically the same solution? So far as I am able to determine, the underlying concepts by which psychophysical interaction is inferred by Eccles do not differ in any relevant respect from those which I have presented as mentalist monism. In searching the arguments and evidence advanced by Eccles (POPPER & ECCLES, 1977) one finds much the same reasoning (see pp. 361–362 and the Summary on p. 373) that I have used to support my own concept of consciousness (cf. SPERRY, 1952–1970*a*,*b*). The phraseology and emphasis are somewhat different and some different neural examples of the principles are introduced, but the conceptual model for mind–brain interaction that is inferred seems entirely consistent and certainly no distinct alternative is offered.

Eccles emphasizes with italics (p. 362) that 'A key component of the hypothesis is that unity of conscious experience is provided by the mind and not by the neural machinery', and this point is again stressed in Dialogue VIII, p. 512, and again in his Gifford Lectures (Eccles, 1979). Here we are in full accord. I too have made precisely the same point (SPERRY, 1952) stating, 'In the scheme proposed here, it is contended that unity in subjective experience does not derive from any kind of parallel unity in the brain processes. Conscious unity is conceived rather as a functional or operational derivative', and 'There need be little or nothing of a unitary nature about the physiological processes themselves.' In his earlier thinking Eccles had given priority to quite a different concept, expressed in terms of extraphysical 'ghostly influences' affecting the course of synaptic events (ECCLES, 1953). I have since referred to and consistently reiterated the above explanation of mental unity in reference to the role of the cerebral commissures and to the 'graininess' problem (SPERRY, 1965–1978), emphasizing that the subjective unity does not correlate with the array of excitatory details comprising the infrastructure of the brain process but rather with the holistic 'mental' properties.

In a reflective appraisal near the end of their volume, Eccles (POPPER & ECCLES, 1977, p. 552) observes, 'As we have developed our hypothesis, we have returned to the views of past philosophies that the mental phenomena are now ascendant again over the material phenomena.' Similarly, I too from the start have described the hypothesis as one that 'puts mind back over matter ...' (SPERRY, 1965); 'would restore mind to its old prestigious position over matter' (SPERRY, 1970*a*). That our key concepts for this and for mind–brain interaction in general are essentially one and the same is further indicated where Eccles (POPPER & ECCLES, 1977, p. 373) ends the condensed summary of his hypothesis with the statement, 'Sperry has made a similar proposal (SPERRY, 1969)' and concludes another 'very brief summary or outline of the theory ...' (p. 495) with the statement, 'Thus, in agreement with Sperry, it is postulated that the self-conscious mind exercises a superior interpretative and controlling role upon the neural events.'

When we turn to the solution to the mind–brain problem upheld by Sir Karl Popper, we find it is also basically the same, but the history of its acquisition is quite different. Prior to 1965, Popper's support of dualism rested mainly on the argument that no causal

physical theory of the descriptive, argumentative functions of language is possible. Products of the mind, like myths, abstractions and mathematical formulas cannot be accounted for by the laws of physiology or physics (POPPER, 1962). During the years in which this argument was propounded, it failed by itself to have much influence in countering physicalist objections that products of the mind have neural correlates and that these products of the mind, like other mental entities, were better interpreted in parallelistic terms as being epiphenomena, inner aspects of, or identical to their neurological correlates. As expressed by OPPENHEIMER & PUTNAM (1958):

> It is not sufficient, for example, simply to advance the claim that certain phenomena considered to be specifically human, such as the use of verbal language in an abstract and generalized way, can never be explained on the basis of neurophysiological theory, or to make the claim that this conceptual capacity distinguishes man in principle and not only in degree from nonhuman animals.

In 1965, Popper proposed a new solution to the mind–brain relation that was exactly what his earlier arguments had been looking for, and which has since become a major theme of his philosophy (POPPER, 1978). In a lecture devoted firstly to a discussion of physical indeterminism, and in a departure from his prior long-time concerns with the logic of knowing, POPPER (1972) added a second theme concerning some revised perspectives on evolution which he then extended to include the body–mind problem. He emerged with what seems to be basically the same view of evolution and the mind–brain relation that I too had proposed a year earlier in my James Arthur Lecture (SPERRY, 1964). In essence, the idea of emerging hierarchic controls is applied to the mind–brain relation. This 1965 switch in Popper's philosophy from a position in which evolutionary theory was held to be tautological, explaining almost nothing, to one in which it explains almost everything was offered with 'many apologies', as a development for which he was obliged 'to eat humble pie'. In line with the main theme of his lecture, a 'plastic' indeterminacy of the emergent controls was emphasized but the degree of looseness or tightness in the controls is not a critical part of the argument.

Because these concepts concerning hierarchic organization and 'downward' control are crucial both to the Popper–Eccles volume and to the present paper, I restate them with exact quotes:

> Evolution keeps complicating the universe by adding new phenomena that have new properties and new forces and that are regulated by new scientific principles and new scientific laws—all for future scientists in their respective disciplines to discover and formulate. Note also that the old simple laws and primeval forces of the hydrogen age never get lost or cancelled in the process of compounding the compounds. They do, however, get superseded, overwhelmed, and outclassed by the higher-level forces as these successively appear at the atomic, the molecular and the cellular and higher levels (SPERRY, 1964).
>
> ... recall that a molecule in many respects is the master of its inner atoms and electrons. The latter are hauled and forced about in chemical interactions by the overall configurational properties of the whole molecule. At the same time, if our given molecule is itself part of a single-celled organism such as paramecium, it in turn is obliged, with all its parts and its partners, to follow along a trail of events in time and space determined largely by the extrinsic overall dynamics of *Paramecium caudatum*. When it comes to brains, remember that the simpler electric, atomic, molecular, and cellular forces and laws, though still present and operating, have been superseded by the configurational forces of higher-level mechanisms. At the top, in the human brain, these include the powers of perception, cognition, reason, judgment, and the like, the operational, causal effects and forces of which are equally or more potent in brain dynamics than are the outclassed inner chemical forces (SPERRY, 1964).

Note that this statement includes the basic key concepts on which the Popper–Eccles case for mind–brain interaction mainly rests, i.e. the downward causal control influence of higher emergent (mental) over lower (neural) entities, and the fact that the mental and neural events are different kinds of phenomena regulated by different kinds of laws and forces.

Hence, from very different backgrounds, Popper and I had arrived by 1965 at the same answer to Eccles's problem. Popper presented his as an answer to 'a new view of evolution' and 'a different view of the world'. I presented mine as 'a scientific theory of mind' and 'a long-sought unifying view of man in nature'. We both offered our view as a new solution to the mind–body problem. When one considers that this new turn in Popper's thinking had not appeared in his extensive philosophical publications over the previous 40 years, the timing of these convergent developments is remarkable.

In Popper's case, his new solution did not become generally available apparently, except by offprint request, until the lecture came to be published in 1972 among other philosophic essays in the volume *Objective Knowledge* (POPPER, 1972). Even Popper's own thinking seems curiously to have been little influenced during this interim. His long article 'On the Theory of the Objective Mind', prepared for the 1972 volume out of two previous papers from 1968 and 1970, introduces his 'three world' terminology. It deals with a subject that, unlike the 1965 lecture, almost cries for the use and application of the new mind–brain solution and different view of the world, yet this goes unmentioned. Even in his subsection on the causal relations between the three worlds, he does not refer to his new solution for the control of brain by mind, but instead adds a footnote on the word 'interact' to explain he is using it 'in a wide sense so as not to exclude psychophysical parallelism'.

DETERMINISM VERSUS INDETERMINISM

Another main theme of Popper's philosophy, indeterminism, is applied to the mind–brain relation. In

this we are in fundamental disagreement. I favor determinism of an emergent, mentalist form that follows directly and logically from my concept of mind as causal (SPERRY, 1964; 1976*b*). In contrast to Popper, I hold that every time the elements of creation, whether atoms or concepts, are put together in the same way under the same conditions, that the same new properties would emerge and that the emergent process is, therefore causal and deterministic. To this extent and in this sense it may also be said to be, in principle, predictable though generally, with few exceptions, it is not so in practice. Rather than viewing the mind of man as a 'first cause' or 'prime mover' (POPPER, 1962; POPPER & ECCLES, 1977), I see the brain as a tremendous generator of emergent novel phenomena that then exert supercedant control over lower-level activities. The higher-level functional entities of inner experience have their own dynamics in cerebral activity and, contrary to Popper's interpretation of my view (POPPER & ECCLES, 1977, p. 209), they also 'interact causally with one another at their own level as entities' (SPERRY, 1969*b*). But the creative process is not indeterminant. The laws of causation are nowhere broken or open (excepting *perhaps* in quantum-level indeterminacy which is here irrelevant). It is all part of a continuous hierarchic manifold, a one-world continuum.

On these terms, human decision-making is not indeterminant but self-determinant. Everyone normally wants to have control over what he does and to determine his own choices in accordance with his own wishes. This is exactly the kind of control our mind–brain model provides (SPERRY, 1976*b*; 1977*b*). But this is not freedom from causal determinacy. A person may be relatively free in this view from much that goes on around him, but he is not free from his own inner self. The emphasis here is the diametric converse of the behaviorist contention that 'ideas, motives, and feelings have no part in determining conduct and therefore no part in explaining it' (BLANSHARD & SKINNER, 1967; SKINNER, 1971). Even Skinner, however, seems in recent years to have withdrawn from his former stance to a point where his present position (SKINNER, 1974) is no longer distinctive. In that great complex of external and internal determinants that control behavior, one can pick out for emphasis either the environmental factors or those of the inner self. From my standpoint, it is the latter that especially tend to distinguish man, while the former are more characteristic of animals and increasingly so as one descends the phylogenetic scale. The self-determinants in man include the stored memories of a lifetime, value systems, both innate and acquired, plus all the various mental powers of cognition, reasoning, intuition, etc.

In any case, it has become evident that Popper's philosophical arguments for mind–brain interaction have become greatly strengthened by having the older pre-1964 logic of neuroscience countered on its own grounds. Conversely, my own concepts of mental phenomena as causal determinants in brain processing are extended and enriched particularly in the upper linguistic and epistemological levels by the insights of Popper. I should also make clear at this point that in reading Popper's work for the first time for this occasion, I was repeatedly impressed with the great extent, particularly in regard to his general positions on epistemology, to which I feel we are in strong and warm accord. The present discussion, and concern for the impact of dualist ideology, brings a disproportionate emphasis on our relative differences.

IS CONSCIOUS EXPERIENCE CAUSAL—OR ONLY ITS NEURAL CORRELATES?

This long, chronological approach may help to clarify the following: The difference between the view of Eccles today and his position in 1964, and similarly the sudden rise during this same period in the scientific acceptance of mental entities as explanatory constructs, as well as the recent new strength of Popper's dualist arguments, all depend in a very critical way on the appearance of a logical alternative by which to refute the traditional behaviorist–materialist paradigm. The new availability of a logical answer contradicting our earlier reasoning that consciousness is acausal and unnecessary for a complete account of brain function meant that the multiple subjectivist pressures toward humanism, cognitivism and mentalism were no longer held at bay by behaviorist theory. The logical deterrents to dualism also were correspondingly reduced. The one new concept that appears to have the logical qualifications and that can be said to make the interaction of such different things as physical and mental states now seem plausible, where in 1964 it had seemed inconceivable, is the concept of the mind–brain relation which Popper and Eccles make the main thesis of their book and on which they very largely build their argument for dualist interactionism, and it is the concept that I too have proposed.

No other development is visible during this period that serves to distinguish between the causal potency of mental experience *per se* and that of its neural correlates, providing for the former over and above the latter, in direct contradiction to behaviorist theory. The increasingly frequent references of late to the evolutionary survival value of consciousness as evidence of its causal usefulness (GRAY, 1971) was for many decades effectively rejected on the grounds that it is the neural correlates that are causal and have survival value, not their conscious qualities. Similarly, recent advances in cognitive and humanistic psychology now expressed in terms of the causal role of mental images and other subjective phenomena, are equally interpretable, as in the past, on behaviorist terms that recognize the causality of the neural correlates of the subjective phenomena, not the subjective qualities themselves. New developments in the mind–brain identity position, the recent 'consciousness'

movements in clinical and humanistic psychology, and the counterculture developments of the 1960s have all been chronologically and otherwise associated, but also similarly fail to furnish any critical reasoning that would distinguish between the causal efficacy of consciousness and that of its neural correlates, or to otherwise refute, so far as science is concerned, the long dominant materialist–behaviorist paradigm. The one development that does this and presents a logical and plausible alternative, is the modified concept of mind as a causal, functional emergent.

It is the idea, in brief, that conscious phenomena as emergent functional properties of brain processing exert an active control role as causal determinants in shaping the flow patterns of cerebral excitation. Once generated from neural events, the higher order mental patterns and programs have their own subjective qualities and progress, operate and interact by their own causal laws and principles which are different from and cannot be reduced to those of neurophysiology, as explained further below. Compared to the physiological processes, the conscious events are more molar, being determined by configurational or organizational interrelations in neuronal functions. The mental entities transcend the physiological just as the physiological transcends the molecular, the molecular, the atomic and subatomic, etc. The mental forces do not violate, disturb or intervene in neuronal activity but they do supervene. Interaction is mutually reciprocal between the neural and mental levels in the nested brain hierarchies. Multilevel and interlevel determinism is emphasized in addition to the one-level sequential causation more traditionally dealt with. This idea is very different from those of extraphysical ghostly intervention at synapses and of indeterministic influences on which Eccles and Popper had earlier relied. The question at issue is whether this form of psychophysical interaction is fundamentally monistic as I interpret it or whether it is dualistic as presented by Popper and Eccles.

In following up this question we want to first recognize that Popper and Eccles go well beyond the given formula for mind–brain interaction to promote correlative concepts and final overall positions that are genuinely dualistic. Eccles's description of the conscious self as having supernatural origins and as something that survives death of the brain, and Popper's concepts of unembodied 'world 3' entities existing independently of any material substrate are distinct examples. Elsewhere in their writings, many implications can be found where they discuss the loose, open and indeterministic nature of the liaison between mind and brain that leaves no doubt that they both have something genuinely dualistic in mind. The difficulty is that these dualistic features are indistinguishably mixed in and fused with the given theory for mind–brain interaction that itself has stood up under criticism and is regarded by many of us as being definitely monistic. Throughout the volume, it is implied that their dualistic extensions and additions are both consistent with, and supported by, the emergent causal model for mind–brain interaction.

Because this model combines features from both of the earlier classical opposing philosophies of monist materialism on the one hand and dualist mentalism on the other, it was presented as a compromise view (SPERRY, 1969; 1970*b*; 1976*c*), and could have been labeled either way at the outset to favor either alternative (given certain qualifications and some redefinitions). It is entirely understandable that Popper and Eccles with their prior commitments to dualism on other grounds should try to make the new compromise as consistent as possible with their earlier thinking. I similarly could have presented it, for example, as 'enlightened physicalism', 'neomaterialism', 'emergentist, cognitivist or mentalist materialism', 'nonreductive materialism', etc. In what follows I will try to outline briefly the reasons for presenting this interactionist model as neither dualistic nor materialistic. I think it combines features that separately exclude it from both the foregoing and that it is best recognized as a fundamentally distinct alternative. From here on it may be understood that my comments will be confined strictly to my own version of the model with which I am directly familar. As I interpret it, this concept of the mind–brain relation not only refutes the doctrines of behaviorism and materialism, mechanistic determinism and reductionism, as Popper and Eccles correctly infer, but also and with equal force, strongly discounts dualism. By explaining conscious experience in monistic terms we undermine dualism at its source and point of strongest support, leaving for dualism only abstract arguments like those of Plato and Popper and observations like those from parapsychology (BELOFF, 1962).

EMERGENT DETERMINISM

It will be helpful as we proceed to have in mind some further concrete examples of the principles of emergent (holist) control as illustrated at different levels in some simpler and more familiar physical systems. I have earlier (SPERRY, 1969*b*) used the example of how a wheel rolling downhill carries its atoms and molecules through a course in time and space and to a fate determined by the overall system properties of the wheel as a whole and regardless of the inclination of the individual atoms and molecules. The atoms and molecules are caught up and overpowered by the higher properties of the whole. One can compare the rolling wheel to an ongoing brain process or a progressing train of thought in which the overall properties of the brain process, as a coherent organizational entity, determine the timing and spacing of the firing patterns within its neuronal infrastructure. The control works both ways; hence, mind–brain 'interaction'. The subsystem components determine collectively the properties of the whole at each level and these in turn determine the time/space course and

other relational properties of the components. The organism and its component cells and organs is another familiar example. The principles are universal.

An example I come back to for classroom illustration contrasts the programming determinants in a television receiver with the electronic and other physical interactions involved in its operation. Complete knowledge of the electronic and physical theory that enables one to fully understand, build and repair the appliance, is no help to explain why Mary struck John on channel 4, or what caused the building to collapse on 2, or the laughter on 7. There is no way that these, or the political message on channel 5, can be explained in terms of the laws and concepts of electronics. They involve a different order or level of interaction. Yet these higher order, supervening, program variables do control at each instant, and determine the space–time course of the electron flow patterns to the screen and throughout the set—just as a train of thought controls the patterns of impulse firing in the brain. The shift to a new program or to a new channel can be compared to a shift in the brain to a new mental set, focus of attention, or to a new thought sequence (SPERRY, 1965). Popper would presumably allocate the programs of television to a separate world ('worlds' within 'worlds'?). Although the allocation of such human artifacts to a distinct separate world proves helpful in some ways and interesting in its original form as a philosophic conjecture, the current promotion of the separate worlds with a capital 'W' in a true dualistic sense seems fundamentally inaccurate and misleading.

The television analogy breaks down if pushed too far, of course, in that the superimposed programs of television are linearly traceable to the recording studio, whereas the brain, by contrast, is largely a self-programming, self-energizing system. It creates its own superseding mental programs with its own built-in subjective generators calling also on a lifetime of internal memories and an elaborate built-in system of value controls (PUGH, 1977) and homeostatic regulators. Also, the programs passing through the television monitor lack the internal interaction and competition of those of the brain, and also the self-developing, originative properties as well as an internal selector of the programs to be attended to.

The conscious programs of the brain may be presumed to be created in activity that lies beyond and is different from that occurring in the geniculostriate system. The difference we envisage here is not in respect to events at the neuronal level but in more systemic, organizational, relational, configurational aspects and design features of the cerebral integration. The special central system for consciousness, or the conscious Self, must include a constant registration of the changing body schema (so strong it tends to persist after limb amputations) and in reference to which sensory input is consciously perceived, plus a feeling for the volitional command of the system (SPERRY, 1952), plus also the relating of both these to sensory inputs, to memory, and to emotional values and homeostatic needs. The conscious attentional component in this central metasystem may be only a small surface feature of the whole vast complex of cerebral intergration. The crucial features of the central self system are presumably innate in each species and largely preorganized independently of sensory input.

It is important to recognize that the term 'interaction' applies in these examples only in the general sense in which it has been used in the history of psychology and philosophy to imply a causal influence between mind and brain. I have stressed that the term 'interaction' is not to imply that the mental forces intervene in, or disturb or disrupt the physiology or chemistry of the brain, but only that they supervene, like TV programs over the electronic processes. No interruption or violation of the laws of physiology is involved. I infer that Popper and Eccles also use the term mostly in the same way and only rarely here and there in the more specific sense of an actual disturbance of physiological events, as MACKAY (1978) seems to have misinterpreted their meaning.

MONISM VERSUS DUALISM

Given our original description of the theory and its consistent reiteration, along with illustrative examples like the foregoing (SPERRY, 1964–1972), it is not easy to understand how this concept of the mind–brain relation could be taken as support for dualism. Firstly, it fails to satisfy the classic philosophic definition of dualism as two different forms or states of existence neither of which is reducible to terms of the other. Our theory describes the mental states as being built of, composed and constituted of physiological and physicochemical elements, and thus, in the sense of the definition, reducible to these. It needs to be explained here that much confusion has arisen from use of this term 'reducible' in two quite different senses in different contexts. In common usage a building is said to be reduced to rubble by an earthquake. This is denied, however, in philosophic, holist-reductionist dispute on the contention that in the reduction process, even with careful disassembly, the building as such has been lost and therefore has not been, and cannot be, in principle, reduced to its parts. It is only in this latter specialized sense, and not in the common sense of the above definition or dictionary usage that I describe the mental events as not reducible to brain physiology.

The reason that mental or other entities cannot be thus reduced to the parts may be understood more easily if one thinks of a given entity not as a system of just material components, but as a combined space–time–mass–energy manifold. Think of space being bent around and molded by the material parts and time as similarly defined by events in temporal and moving systems with the space–time components both arranged also in vertical nested hierarchies cor-

responding to and filling in around the material elements and defined by their relative positions and timing. The process of reducing an entity to its material components, physically or conceptually, inevitably destroys the space–time components at the affected level. These last components from the space–time manifold, interfusing with, shaped by, and demarcated by the material components, are highly critical in determining the causal and other distinguishing properties of any system as a whole. The spacing and timing of the parts with reference to one another largely determine the qualities and causal relations of the whole but the laws for the material components fail to include these space–time factors. Attempts to recognize them in so-called 'collective' and 'cooperative' effects tend to fall short of an adequate recognition of the basic importance of the space–time elements. This is why quantum mechanics is of little help in explaining physical reality at orders much above the quantum level.

None of this is to reject the value of reduction as a method in science or as a means to gain understanding in general. The properties of any entity are determined largely (but not entirely, and in some cases more than others) by the properties of its parts. It obviously helps enormously, as a rule, to know how and of what anything is composed. Further reduction to the composition of the parts of the parts, and so on, becomes increasingly less explanatory of operations at the higher, starting level. Though brain quarks and gluons are not of particular relevance to behavioral science, one can expect that in many respects brain physiology in its upper dimensions may become to behavior and cognitive processing what molecular theory is to chemistry. It is only the reductionist reasoning that therefore things can be reduced to 'nothing but' their parts that is rejected or that all science can be reduced, in principle, to a basic unity in one fundamental discipline, or that the 'essence' of anything is to be sought in its components.

Along with the failure to qualify as dualism by definition, our proposed mind–brain model also is nondualistic in that it makes mind and brain inseparable parts of the same continuous hierarchy the great bulk of which, by common agreement, is not dualistic. It becomes illogical to make a special exception of the principle at the one level of mind and not at those above and below. On the proposed scheme, one can proceed continuously in the same universe of discourse, following the path of evolution, from subatomic elements in the brain up through molecules, cells and nerve circuits to brain processes with conscious properties and on upward through higher compounds all within the one 'this-world' mode of existence.

Dualism would seem to be further contradicted in our description of subjective meaning as a functional derivative rather than a brain copy or a spatiotemporal transform (SPERRY, 1952). As an emergent functional attribute of brain activity, conscious experience is inextricably linked to, and inseparable from, the functioning brain. It is only in the functional relations within the matrix of brain processing that the subjective qualities appear and have their meaning. The subjective effects are generated by, and exist only by virtue of, brain activity. Even where higher order mental forms are compounded of lower level mental entities, as we assume to be the case, the entire hierarchy is still embodied in, dependent on, and inseparable from the physiological substructure.

Much the same solution to the mind–brain problem has been arrived at recently by MACKAY (1978) who presents it in the more restricted terminology of information theory using for illustration the example of goal-directed operations in a computer. The same example was offered by MacKay in 1964 couched in 'dual aspect' theory when he held the view (most favored in neuroscience at that time) that the mental and the physical are complementary aspects of one and the same process where 'no physical action waits on anything but another physical action' (MACKAY 1966, p. 438). In those years, MacKay granted the physical determinancy for the CNS holding conscious brain activity to be predictable in principle, in objective terms from a knowledge of the precedent physical determinants (provided one did not reveal the prediction of a predicted sequence to a person involved in the prediction). The emergent nature of the mental controls as we now conceive them in a vertical or nested hierarchy, and the manner in which they supersede, rather than merely parallel as an inner aspect, the physiological determinants were missed by MacKay in 1964 but apparently are accepted in his 1978 version, along with a new recognition of the causal efficacy of consciousness. These changes now bring our respective views into rather close accord with respect to those features most directly relevant to the mind–brain problem.

Apparently unacquainted with the history of these conceptual developments and the original concepts from which Popper and Eccles argue, MACKAY (1978) misinterprets the kind of interactionism they have in mind and then finds it 'astonishing' how close and natural a fit can otherwise be made between theirs and his own description. Preserving consistency with his earlier position, MacKay is inclined to emphasize, more than I, the extent to which the proposed alternative is a physicalist rather than a mentalist view. It has to be remembered in this regard that whereas the programs of the computer or television analogies are conceived in physical terms, those of the brain have always been described as *mental* with subjective properties defined as contrast to the physical or material. In any case, I fully agree with MacKay that the arguments and evidence advanced in support of dualist-interactionism in the Popper–Eccles volume are very much open to the kind of alternative interpretation that we propose.

MENTALISM VERSUS MATERIALISM

The explanation of mind in the foregoing terms as an organizational functional property of brain processing, constituted of neuronal and physicochemical activity, and embodied in, and inseparable from the active brain has led to an impression in some cases that this should properly be interpreted as therefore an essentially materialist view. Some further reasons for defining it instead as mentalist (or cognitivist) can be outlined as follows: The principal feature of this model is the new recognition it gives to the primacy of subjective mental phenomena in scientific explanation and the higher level control role accorded mental or cognitive phenomena as causal determinants, over and above their neural correlates. It is characterized as placing 'mind back over matter', and as 'a scheme that idealizes ideas and ideals over physical and chemical interactions, nerve impulse traffic, and DNA. It is a brain model in which conscious mental psychic forces are recognized to be the crowning achievement of some five hundred million years or more of evolution' (SPERRY, 1965). As such, it conforms to the common textbook and lay definitions of the terms mental and mentalism. The subjective qualities are recognized to be real and causal in their own right, as subjectively experienced, and to be of very different quality from the neural, molecular and other material components of which they are built. Because mind and matter, the mental and the physical, have long been defined as direct contrasts and given meaning in terms of their opposites, this proposed recognition of the causal primacy of subjective mental qualities would seem to logically exclude materialism.

In particular, the present position represents a direct refutation of what materialism had long come to stand for over many decades in science, philosophy and humanist thinking generally. Materialist behaviorism asserting the principle that ideas, motives and feelings have no part in determining conduct and therefore no part in explaining it (SKINNER, 1967) had gone, in the extreme, to denying even the existence of consciousness in any form and, at the least, denied as a founding central premise any causal efficacy of conscious or mental forces in brain processing. Materialist philosophy and the so-called psychophysical identity theory was being advanced during the 1960s on the contention that 'man is nothing but a material object, having none but physical properties'. And 'Science can give a complete account of man in purely physicochemical terms' (ARMSTRONG, 1968). The 'Unity of Science' movement, closely aligned with identity theory, held that the laws of science can all be reduced eventually, in principle, to the laws of a single basic discipline (CARNAP, 1938; FEIGL, 1953; OPPENHEIM & PUTNAM, 1958). Physical science was seeking answers to all nature in terms of 'the four fundamental forces' with hopes for a further unifying field theory to describe the essence of reality. Our view arose in the mid-1960s, in direct opposition to all of these and related materialistic, mechanistic and reductionist trends.

Meantime mind–brain identity theory which has become the strongest thrust in materialist philosophy has undergone substantial changes during the last decade. In its initial form as a semantic twist to the old 'double aspect' view that goes back at least to Spinoza, it was described as a 'dual access' or 'double language' theory (FEIGL, 1967) and was strongly reductivist. In particular, it held that a complete account of brain processing is possible, in principle, in neural terms only without resorting to subjective language or mental terms. Unlike the epiphenomenal view, or the emergent, double aspect or interactionist views, identity theory itself seems to provide no new concrete concepts to the mind–brain problem, only different semantic approaches. Our introduction in the mid-1960s of the opposing view of consciousness as a nonreductive emergent with causal potency and downward control has been followed by a spate of new semantic transformations in identity theory in which a new emphasis is put on the causality of consciousness and on emergent concepts under terms such as organizational, configurational, holistic, collective, and the like (GLOBUS, 1973; WILSON, 1976; PERRY, 1978; SMART, 1978; WARD, 1978). In all cases the changes appear to bring these two initially contrasting approaches into closer convergence. The argument from identity philosophy today seems accordingly to be not so much that our emergent determinist view is incorrect, but rather that this is what identity theory actually should have been taken to imply all along. We thus have the curious result that our latest mind–brain model is today being identified with materialism on the one side and with dualism on the other.

Finally, in defense of the mentalist rather than the materialist designation, I would only add the following: If there is anything in this world that has been commonly defined as a contrast to the material or physical, it is the intangibles of conscious experience. The psychological contents of mind from their first recognition in language, philosophy and science, have been treated by tradition as opposites of physical and material in the mind–matter dichotomy. Accordingly, a position can hardly be called materialist if its very essence and reason for being is a new antimaterialist stress on the existence and functional primacy of mental phenomena and their role as high level causal determinants in brain function, obeying laws that are different in kind from those of their constituent material, neuronal and electrochemical processes. A mentalist is defined in behavioral science as one who, in opposition to behaviorist doctrine contends that mental entities and laws are involved in determining behavior and are needed to explain it. The concept of consciousness as causal emergent has been presented from the outset as a view that restores to science the common-sense impression (overruled during the behaviorist–materialist era) that we do indeed have

mind and mental faculties over and above, and different from, our brain physiology—just as we have cellular properties that are over and above and different from their molecular constituents.

The distinction between the mentalist paradigm and that of materialism or behaviorism, though important within psychology, is less-critical overall than that between monism and dualism. If common usage in the long run should tend to favor the stretching of the meaning of materialism and/or physicalism to encompass mental phenomena in the causal, emergent, embodied, non-reductive form we now envisage, there would be no great loss provided there was no resultant confusion in regard to the actual conceptual changes themselves and their new implications and connotations. Of all the questions one can ask about conscious experience, there is none for which the answer has more profound and far-ranging implications than the question of whether or not consciousness is causal. The alternative answers lead to basically different paradigms for science, philosophy and culture in general.

If the concern with terminology begins to seem over done, it should be remembered that labels and their connotations and the right hemisphere impressions they carry are often more important in human decision-making than are the more precisely formulated logical concepts and facts they stand for. When Popper and Eccles, representing modern philosophy and neuroscience, jointly proclaim arguments and beliefs in dualism, the supernatural and in unembodied worlds of existence, the repercussions quickly extend beyond professional borders to influence attitudes and faith-belief systems in society at large. The result has been a major setback for those of us (for example, BURHOE, 1975; PUGH, 1977; SPERRY, 1977) who see hope for the future and for the very aims and ideals that I think Sir John and Sir Karl strive for, to lie in replacing old dualist perspectives, values and beliefs, dualist theologies and related mythological worldview guidelines of the past with a new unifying holistic–monistic interpretation of reality as an ultimate reference frame in the search for criteria of value and meaning.

Acknowledgements—This article was prepared initially for a volume on mind–brain interaction edited by D. L. WILSON, P. GLOTZBACH and M. RINGLE that was to have included a response from KARL POPPER and JOHN ECCLES, but later had to be cancelled. Aided by the F. P. Hixon Fund of the California Institute of Technology. I thank JERRE LEVY, COLWYN TREVARTHEN, EVELYN TENG and EDWARD REED for helpful comments on an earlier draft of the manuscript.

REFERENCES

ARMSTRONG D. M. (1968) *A Materialist Theory of the Mind*. Routledge & Kegan Paul, London.

BELOFF J. (1962) *The Existence of Mind*. The Citadel Press, New York.

BINDRA D. (1970) The problem of subjective experience: Puzzlement on reading R. W. Sperry's 'A modified concept of consciousness.' *Psychol. Rev.* **77**, 581–584.

BLANSHARD B. & SKINNER B. F. (1967) The problem of consciousness—A debate. *Philosophy and Phenomenological Research* **27**, 317–337. Reprinted in *Theories in Contemporary Psychology* (1976) (eds MARX M. H. & GOODSON F. E.), pp. 205–223. Macmillan, New York.

BUNGE M. (1977) Emergence and the mind. *Neuroscience* **2**, 501–509.

BURHOE R. W. (1975) The human prospect and the 'Lord of History'. *Zygon* **10**, 299–375.

CARNAP R. (1938) *Logical Foundations of the Unity of Science, International Encyclopedia of Unified Science*, Vol. I, pp. 42–62. University of Chicago Press, Chicago.

DEMBER W. N. (1974) Motivation and the cognitive revolution. *Am. Psychol.* **29**, 161–168.

ECCLES J. C. (1953) *The Neurophysiological Basis of Mind: The Principles of Neurophysiology*. Clarendon Press, Oxford.

ECCLES J. C. (ed.) (1966) *Brain and Conscious Experience*. Springer, New York.

ECCLES J. C. (1968) The importance of brain research for the educational, cultural and scientific future of mankind. *Perspect. Biol. Med.* **12**, 61–68.

ECCLES J. C. (1973) Brain, speech and consciousness. *Die Naturwissenschaften* **60**, 167–176.

ECCLES J. C. (1979) *The Human Mystery* (Gifford Lectures, 1978). Springer, Berlin.

FEIGL H. (1953) Unity of science and unitary science. In *Readings in the Philosophy of Science* (eds Feigl H. & Brodbeck M.), pp. 382–384. Appleton-Century-Crofts, New York.

FEIGL H. (1967) *The 'Mental' and the 'Physical'*. University of Minnesota Press, Minneapolis.

FREEMAN J. D. (1979) Towards an anthropology both scientific and humanistic. *Canberra Anthropology* **1**, 44–69.

GLOBUS G. G. (1973) Consciousness and brain—I. The identity thesis. *Archs gen. Psychiat.* **29**, 153–160.

GRAY J. A. (1971) The mind–brain identity theory as a scientific hypothesis. *Philosoph. Quart.* **21**, 247–254.

JOHN E. R. (1976) A model for consciousness. In *Consciousness and Self Regulation* (eds SCHWARTZ G. E. & SHAPIRO D.). Plenum Press, New York.

KANTOR J. R. (1978) Cognition as events and as psychic constructions. *Psychol. Rec.* **28**, 329–342.

KÖHLER W. (1961) The mind–body problem. In *Dimensions of Mind* (ed. HOOK S.), pp. 15–32. Collier Books, New York.

MACKAY D. M. (1966) Conscious control of action. In *Brain and Conscious Experience* (ed. ECCLES J. C.). Springer, Heidelberg.

MACKAY D. M. (1978) Selves and brains. *Neuroscience* **3**, 599–606.